Patellar Tendinopathy with Intra-tendinous Alteration on MRI may be related to Patellofemoral Dysplasia

Tscholl, Philippe M ; Biedert, Roland M ; Wanivenhaus, Florian ; Fucentese, Sandro F

Abstract: Patellar tendinopathy (PT) is a frequent overuse-injury of the extensor knee apparatus whereas as up to 30% of the athletes might suffer from persisting symptoms during their entire career. In the present case-control study, 47 patients (30.8±11.4 years) with PT with intra-tendinous alteration (PTita) of a minimum of 25% of the axial surface on MRI and minimum Blazina score of II (pain during without limiting sports activity) were included; MR images were analysed for trochlear geometry, patellar height/tilt, and tibial tubercle trochlear groove distance (TT-TG). The control group (CG) comprised 87 age- and gender-matched patients without history of anterior knee pain or lateral patellar instability. It was hypothised that patients with PT might be related to patellofemoral dysplasia. It was found, that the patella was significantly higher in PT patients compared to the CG (patellotrochlear index (PT-I): 0.33 vs 0.37, p=0.014; Insall-Salvati index (InSa): 1.18 vs 1.07, p=0.004). PT-I was above the cut-off value in 10.6% of PT knees (CG 5.7%, p=0.27), and InSa in 42.6% (CG 21.8%, p=0.012). TT-TG was significantly higher in PT patients compared to CG (12.0 mm vs 9.9 mm, p=0.002); however, TT-TG was only pathologic (>20 mm) in one patient. The trochlear facet ratio was above the cut-off value in 55.3% of PT patients and 23% of CG (p<0.001), and was significantly greater in PT patients (0.39±0.09) than CG (0.48±0.1, p<0.001). Knees with PT have significantly more morphological characteristics of patellofemoral instability, which needs to be considered especially in recurrent or treatment-refractive cases.

DOI: https://doi.org/10.1111/sms.13033

DR PHILIPPE MATTHIAS TSCHOLL (Orcid ID : 0000-0003-1702-7114)

Article type : Original Article

Patellar Tendinopathy with Intra-tendinous Alteration on MRI may be related to Patellofemoral Dysplasia

Philippe M. Tscholl[1,2], Roland M. Biedert[3], Florian Wanivenhaus[1], Sandro F. Fucentese[1]

[1] Department of Orthopaedic Surgery, Balgrist University Hospital, University of Zurich, Zurich, Switzerland.

[2] Division of Orthopedics and Trauma Surgery, Geneva University Hospital, Geneva, Switzerland.

[3] SportsClinic#1, Wankdorf Center, Bern, Switzerland.

Corresponding addresse: Dr. med. Philippe M. Tscholl, Orthopädische Klinik, Universitätsklinik Balgrist, Forchstrasse 340, CH-8008 Zürich, Switzerland. Tel.: 0041 44 386 11 11. Fax: 0041 44 386 11 09. ph.tscholl@sunrise.ch

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record. Please cite this article as doi: 10.1111/sms.13033

ABSTRACT

Patellar tendinopathy (PT) is a frequent overuse-injury of the extensor knee apparatus whereas as up to 30% of the athletes might suffer from persisting symptoms during their entire career. In the present case-control study, 47 patients (30.8±11.4 years) with PT with intra-tendinous alteration (PTita) of a minimum of ≥ 25% of the axial surface on MRI and minimum Blazina score of II (pain during without limiting sports activity) were included; MR images were analysed for trochlear geometry, patellar height/tilt, and tibial tubercle trochlear groove distance (TT–TG). The control group (CG) comprised 87 age- and gender-matched patients without history of anterior knee pain or lateral patellar instability. It was hypothised that patients with PT might be related to patellofemoral dysplasia. It was found, that the patella was significantly higher in PT patients compared to the CG (patellotrochlear index (PT-I): 0.33 vs 0.37, p=0.014; Insall-Salvati index (InSa): 1.18 vs 1.07, p=0.004). PT-I was above the cut-off value in 10.6% of PT knees (CG 5.7%, p=0.27), and InSa in 42.6% (CG 21.8%, p=0.012). TT–TG was significantly higher in PT patients compared to CG (12.0 mm vs 9.9 mm, p=0.002); however, TT–TG was only pathologic (>20 mm) in one patient. The trochlear facet ratio was above the cut-off value in 55.3% of PT patients and 23% of CG (p<0.001), and was significantly greater in PT patients (0.39±0.09) than CG (0.48±0.1, p<0.001). Knees with PT have significantly more morphological characteristics of patellofemoral instability, which needs to be considered especially in recurrent or treatment-refractive cases.

Keywords: patella alta – overuse injury – trochlear dysplasia – patellofemoral pain – anterior knee pain – jumper's knee – tendinopathy

INTRODUCTION

Patellar tendinopathy (PT) is the clinical term used to describe pain at the distal tip of the patella with or without degenerative changes seen on MRI of the proximal patellar tendon. This is a frequent overuse injury that occurs in 2.5–45% of professional athletes and up to 14% of non-elite athletes[1,2], with prevalence highly dependent on the sporting discipline.[1,3] It causes symptoms that limit athletic performance, and can lead to long-term sports cessation or even withdrawal from sports participation.[1,4] In a retrospective study of 100 athletes clinically diagnosed with PT, only two-thirds returned to sport within 6 months, and 18 were side-lined for more than 1 year.[5] In 48% of these athletes, symptoms commenced before the age of 20 years.[5] Interestingly, patients reported with structural degenerative changes of the patellar tendon were aged 27–33 years in most of the studies.[5-14]

Previous studies have analysed morphological factors such as the patella-patellar tendon angle and the inferior patellar pole size as potential sources of impingement[13] leading to PT with significant intra-tendinous alteration (PTita). However, the inferior patellar pole does not seem to be biomechanically relevant[13] for the development of the degenerative tendinous changes typically observed at the deep fibres of the proximal patellar tendon insertion.[10,15-18] In contrast, the anterior fascicles are stronger and thicker at the proximal patellar tendon insertion than they are posteriorly,[19,20] where they undergo less strain.[21] This unfavourable load and resistance distribution on the deep fibres of the proximal patellar tendon insertion is further increased by patellar maltracking, which is found in 55% of patients with PTisa.[22,23] The underlying anatomical factors causing patellar maltracking are so far unknown.

The purpose of this study was to investigate on the morphology of the patellofemoral joint in patients with PTita, hence patients with anterior knee pain related to clinically diagnosed PT and macroscopic degenerative changes of the proximal patellar tendon on MRI. It was hypothesised that patients with PTita would have more morphological signs of patellofemoral instability in terms of trochlear dysplasia, patella alta, and increased tibial tubercle trochlear groove distance (TT–TG) than a control group without history of any patellofemoral pain.

MATERIAL AND METHODS

Study population

Data collection for this retrospective analysis was retrieved from the electronic university hospital database. All patients diagnosed for PTita on MRI between 2006 and 2013 were included in this study that corresponded to following clinical and MRI findings:

- Clinical findings: pain on palpation of the inferior patellar tip, history of pain during exercise, and minimum score of II on the Blazina scale[24] (I: pain only after activity, II: pain during activity, but does not interfere with participation, III: pain both during and after participation, which interferes with participation, IV: complete tendon disruption).

- MRI findings: hyperintense signal of the proximal patellar tendon. As a mild increase in signal intensity of the proximal patellar insertion may be a coincidental finding in the normal knee,[13] patients were required to have a hyperintense signal in a minimum of 25% of the axial cross-section tendon area (CSA) according to a grade 2 PTita according to Johnson et al.[15] (0: normal tendon shape, 1: increased signal intensity in <25% of the axial CSA, 2: increased signal intensity in 25–50% of axial CSA, 3: increased signal intensity in >50% of axial CSA).

Patients with objective patellofemoral instability (documented dislocation), surgery, or injections to the inferior pole of the patella were excluded. No patient with PTita was found to have a documented patellar dislocation.

A total of 47 knees (9 female and 38 male patients, 30 +/- 11.4 years of age) matched to these criteria. The control group comprised 87 randomly selected age- and gender-matched subjects (29.4 +/- 9.3 years of age, 14.9% female), who had undergone an identical MRI protocol for menisco-ligamentous injury with no history of patellar instability or anterior knee pain.

This retrospective study was performed in accordance with local ethical regulations and written approval was received.

MRI protocol

Imaging was performed with a 1.5 T MR unit (Magnetom Espree and Magnetom Avanto, Siemens Medical Solutions, Erlangen, Germany) or a 3.0 T MR unit (Magnetom, Verio, Siemens Medical Solutions, Erlangen, Germany). Transverse PD TSE FS and T2 trufi3d-weighted, sagittal MR images were scanned of the entire knee (including the region of the entire trochlea to the tibial tubercle). The patient's leg was held in extension in a standard coil with the quadriceps muscle relaxed during scanning.

Measurement methods

A fellowship-trained orthopaedic surgeon with a special interest in patellofemoral pathologies performed all measurements, and the inter-rater reliability was performed with a senior resident in orthopaedics surgery (see Table 1); a specialised musculoskeletal imaging radiologist trained both investigators prior to study commencement. The femoral trochlea was analysed using the following parameters: trochlear dysplasia according to Dejour[25], trochlear sulcus angle, trochlear facet ratio (medial/lateral),[26] trochlear dysplasia,[25] lateral trochlear inclination angle[27] (all measured on the most proximal axial image with full cartilaginous coverage of the trochlea), lateral condyle index,[28] and anteroposterior trochlear measurement (Figure 1).[29]

The patellar height was measured using the Caton-Deschamp index (CD-I), the Insall-Salvati index (InSa-I), and the patellotrochlear index (PT-I) (Figure 2).[30] The patellar tilt[31] was evaluated as a measure of lateralisation. TT–TG was measured according to the method described by Schöttle et al.[32] The cut-off values for the different measurement methods are mentioned in Table 1.

The volume of the PTita was measured on the most proximal transverse MR image below the patellar tip at the patellar tendon insertion (Figure 3).[33,34] The patellar tendon width was divided into the medial, central, and lateral third. The patellar tendon thickness was divided into a superficial layer (according to the fascicles of the galea aponeurotica bridging the quadriceps and the patellar tendon[35]) and a deep layer or "true" patella-tibia layer.

The inter-class correlation coefficient for single measures for all variables was high (0.892, 95% CI 0.664 to 0.982, Table 1).

Statistical analysis

In both groups, the values were calculated as the mean with standard deviations. The values of the patients with PTita and the control group were compared using the Mann-Whitney U test, and the number of knees showing pathologic values were compared by the Chi squared test; $p<0.05$ was considered to indicate statistical significance. Inter-observer reliability was calculated by the intra-class correlation for single measures.

RESULTS

Trochlear morphology

The results are summarized in Table 1. There was a significant difference between the two groups in trochlear shape, knees with PTita having a shorter medial trochlear facet, and a smaller trochlear height medially and centrally than controls (see Figure 1 and 3). No significant difference was found for cranio-caudal length of the lateral trochlea or trochlear dysplasia according to Dejour; 53–58% had no trochlear dysplasia (PTita: 25 of 47, controls: 51 of 87), 40–41% had type A (20 of 47 and 35 of 87, respectively), and 1–4% had type B trochlear dysplasia (2 of 47 and 1 of 87, respectively). No participant in either group had

higher-grade trochlear dysplasia of type C or D with a hypoplastic medial femoral condyle and therefore a convex trochlea on axial imaging.

Patellar height and TT-TG

The patella was significantly higher in patients with PTita than in control subjects according to the InSa-I and the PT-I (Table 1). The overall incidence of patella alta was 10.6–46.9% in the PTita cohort and 5.7–28.7% in control subjects (Table 1).

The TT–TG was significantly increased in patients with PTita compared with controls, however >15mm in 11 knees (23.4%) only.

Analysis of the seven major characteristics of patellofemoral instability (sulcus angle, trochlear facet ratio, lateral trochlear inclination angle, patellar height (on CD-I and PTI), patellar tilt, and TT–TG) revealed that patients with PTita showed an increased number of values above the cut-off value than control subjects (2.8±1.1 vs 2.14±1.2; p=0.032). While more than 10% of knees in the control group had values above the cut-off value of the morphological characteristics of patellofemoral instability, every knee with PTita showed at least one pathological measurement.

Localization of PTita

All PTita were found in the deep layer of the proximal insertion of the patellar tendon (Figure 3), without affecting the superficial fibres originating from the galea aponeurotica. On axial view, the centre of the PTita was found in the medial third in 46.8% (22 of 47 patients) and in the central third in 53.2% (25 of 47 patients). No patient had PTita in the lateral third of the patellar tendon.

DISCUSSION

The main finding of the present study was that patients with moderate to severe PTita had significantly more morphological characteristics of patellofemoral instability than control subjects. PTita patients had significantly higher patellae, the medial trochlea was hypoplastic in height and length, and the lateral vector force on the patella was increased (measured by the TT–TG) compared with control subjects. These factors may all contribute to the patellar maltracking previously reported in patients with PTita,[22] and might have led to the subgroup of patients with anterior knee pain as potentially instable patellae ("instabilitées rotulienne potentielles").[36] Although the absolute difference of the several measurements were small, more than 50% of the knees in the PTita group had a pathologic value in at least 3 out of 7 measurements compared to one out of 4 knees of the control group.

On axial MRI, PTita was located in the medial or central third of the proximal insertion of the patellar tendon. This is in accordance with previous reports that found thickening and sign-alteration at the inferior apex of the patellar tendon at its medial third,[10,14-18,37,38] with tenocyte hyperplasia, angiogenesis, and loss of longitudinal collagen architecture.[16,18,39] This indicates that the origin of this lesion is likely biomechanical.

The major strength of the following study is, the highest number of patients so far described in literature including high-grade PTita on MRI only, contrary to most previous studies including only clinical assessment or Doppler-ultrasound, that has shown to be positive also in asymptomatic.[6]

The classic radiographic signs of patellar instability are trochlear dysplasia, patella alta, increased TT–TG (>20 mm), and negative patellar tilt.[40,41] [41] Further characteristics for patellofemoral dysplasia associated with maltracking or dislocation have been published, such as decreased trochlear facet ratio and lateral inclination angle.[27,41-44] So far, only one publication has reported an association between PT diagnosed on MRI and patella alta[15]; however, there was no control group in their study.[15] Kujala et al.[9] found an association

between anterior knee pain and patella alta in 20 patients with clinically diagnosed 'patellar apicitis' compared with 20 control subjects. In a follow-up study of the same collective, Kettunen et al.[4] concluded that patellar height was also associated with knee symptoms at 15-year follow-up. In two surgical outcome studies including a total of 75 patients with PT, the incidence of patella alta was 0–3.1%[8,18]; however, no other morphologic characteristic of the patellofemoral joint was looked at in their analyses. Culvenor et al.[45] analysed MR images of 26 patients with ultrasound-diagnosed PT and found a trend of increased lateral patellar tilt angle and less strongly of decreased sulcus angle; however, they did not describe the degree of partial tear on MR imaging. These previous findings indicate that patients with PT may have more morphological characteristics leading to patellar instability than control subjects.

It is well accepted that static radiologic measurements of the patellofemoral joint have limitations and might also be an anatomic variant in asymptomatic patients. Patellofemoral instability should ideally be analysed dynamically. When weight-bearing, the patella rises due to quadriceps contraction force. Therefore, every index measuring patella-femoral height will be increased[46]; however, the InSa-I will proportionally increase by the least amount. There is a reported trend for this effect to be even more evident in patients with patellofemoral instability than in control subjects[47]; hence, true patellar height may be even more underestimated. In an MRI study that evaluated dynamic imaging with quadriceps contraction compared with static imaging in patients with patella alta, there was a significant increase in lateral patellar deviation (+20%) and patellar tilt (+39%), and a decreased contact area (19%) in extension.[48] Additionally, contact of the quadriceps tendon with the distal femur in flexion (which reduces patellofemoral pressure and tensile force on the patellar tendon) is delayed in patella alta,[49] indicating that greater contact forces can be expected in patients with patella alta.

The combination of increased tensional forces, patellar maltracking, and lateral patellar tilt ("functional lateralisation", called the J-sign in severe cases) may lead to repetitive microruptures of the tendon at the central or middle third of the proximal patellar tendon insertion, as found in the present study. This hypothesis is supported by associated injuries to the medial retinaculum found in up to 67% of patients with PT and in 25% of patients with medial patellar avulsion fracture.[10,15] Reducing patellar height by applying an infrapatellar strap that reduces the retroversion of the patella in flexion in the sagittal plain was found to reduce peak tension forces of the posterior-medial fascicles on a computational analysis.[23]

The present study had some limitations as it was a purely descriptive and retrospective study referring to a specific group of patients diagnosed as having PTita with structural degenerative changes of the patellar tendon seen on MRI. Patients with PT without structural changes are not represented in this study. To what degree they might differ is unknown. Only static measurements of the patellofemoral joint were possible; no information about patellar tracking was available, nor any other patient referred risk factors such as muscular flexibility, leg axis, BMI, or weight. As morphological characteristics of patellofemoral instability on MRI can be found as a normal variant in some cases, their significance is not ascertained and don't necessarily lead to patellar maltracking.

Future studies in patients with PT with or without PTita are required to investigate on functional outcome parameters in function of trochlear morphology or patellar height; to determine whether patients with jumper's knee and altered patellofemoral morphology and maltracking are at increased risk of being non-responders to non-surgical treatment modalities and whether surgical realignment procedures might be necessary.

CONCLUSION

Symptomatic patients with PTita on MRI show minor signs of trochlear dysplasia. Their patellar height is significantly higher than in controls, with an incidence of patella alta of 11–47%, depending on the measurement method. The pathomechanism of highly degenerative

PT might be a functional patellar lateralisation described in literature for patella alta, with increased tensional forces on the deep medial and central fascicles of the proximal patellar tendon insertion, which are the primary sites of degenerative changes. Future studies are needed to elicit patellofemoral joint biomechanics, especially in patients with therapy-refractory degenerative changes to the patellar tendon, to highlight the importance of further non-surgical and surgical treatment options.

PERSPECTIVE

Patellar tendinopathy is a frequent overuse injury, and can be sports-career ending due to its high recurrence rate. High-grade PTita is regarded as the end-stage of this pathology, which so far has not been described in literature in terms of its patellofemoral joint morphology. According to the present results, knees with PTita are highly associated with patella alta, and show more signs of trochlear dysplasia than controls. Combined high riding patella with a flat trochlea is associated with lateral patellar maltracking and might be the underlying cause of this degenerative tendinous process of the deep proximal medial fibres. Distalizing the patella and improving patellotrochlear congruence might decrease tensile forces on the deep medial fibres of the proximal patellar tendon.[23] Therefore, future treatment strategies, especially in high-grade PT, will need to focus on patellofemoral morphology and patellar tracking more into details.

LEGENDS OF TABLES AND FIGURES

Table 1: Risk factors for patellar instability in patients with patellar tendinopathy with intra-tendinous alteration (PTita) and controls

Figure 1 – Trochlear measurements on axial MRI in a patient with PTita – A) trochlear sulcus angle (alpha), lateral trochlear inclination angle (beta), and B) medial to lateral trochlear facet ratio (m / l), antero-posterior trochlear measurements (M, C, L; width).

Figure 2 – Patellar height measurement – Insall-Salvati Index (a / b), Caton-Deschamp Index (c / d), Patellotrochlear Index (d / e).

Figure 3 – Patellar tendinopathy with intra-tendious alteration on axial and sagittal MR images – with A) a high riding patella, B) no trochlear dysplasia, but a shallow medial femoral condyle and a steep trochlear inclination angle. A hyperintense signal of the patellar tendon is found in the deep fibers of the medial third, and of the superolateral Hoffa fat pad, as an indirect sign of functional patellar lateralization.

REFERENCES

1. Lian OB, Engebretsen L, Bahr R. Prevalence of jumper's knee among elite athletes from different sports: a cross-sectional study. *Am J Sports Med.* 2005;33(4):561-567.
2. Hagglund M, Zwerver J, Ekstrand J. Epidemiology of patellar tendinopathy in elite male soccer players. *Am J Sports Med.* 2011;39(9):1906-1911.
3. Zwerver J, Bredeweg SW, van den Akker-Scheek I. Prevalence of Jumper's knee among nonelite athletes from different sports: a cross-sectional survey. *Am J Sports Med.* 2011;39(9):1984-1988.
4. Kettunen JA, Kvist M, Alanen E, Kujala UM. Long-term prognosis for jumper's knee in male athletes. A prospective follow-up study. *Am J Sports Med.* 2002;30(5):689-692.
5. Cook JL, Khan KM, Harcourt PR, Grant M, Young DA, Bonar SF. A cross sectional study of 100 athletes with jumper's knee managed conservatively and surgically. The Victorian Institute of Sport Tendon Study Group. *British journal of sports medicine.* 1997;31(4):332-336.
6. Cook JL, Khan KM, Kiss ZS, Coleman BD, Griffiths L. Asymptomatic hypoechoic regions on patellar tendon ultrasound: A 4-year clinical and ultrasound followup of 46 tendons. *Scand J Med Sci Sports.* 2001;11(6):321-327.
7. Crossley KM, Thancanamootoo K, Metcalf BR, Cook JL, Purdam CR, Warden SJ. Clinical features of patellar tendinopathy and their implications for rehabilitation. *J Orthop Res.* 2007;25(9):1164-1175.

8. Cucurulo T, Louis ML, Thaunat M, Franceschi JP. Surgical treatment of patellar tendinopathy in athletes. A retrospective multicentric study. *Orthopaedics & traumatology, surgery & research : OTSR.* 2009;95(8 Suppl 1):S78-84.
9. Kujala UM, Osterman K, Kvist M, Aalto T, Friberg O. Factors predisposing to patellar chondropathy and patellar apicitis in athletes. *Int Orthop.* 1986;10(3):195-200.
10. McLoughlin RF, Raber EL, Vellet AD, Wiley JP, Bray RC. Patellar tendinitis: MR imaging features, with suggested pathogenesis and proposed classification. *Radiology.* 1995;197(3):843-848.
11. Marcheggiani Muccioli GM, Zaffagnini S, Tsapralis K, et al. Open versus arthroscopic surgical treatment of chronic proximal patellar tendinopathy. A systematic review. *Knee Surg Sports Traumatol Arthrosc.* 2013;21:351-357.
12. Santander J, Zarba E, Iraporda H, Puleo S. Can arthroscopically assisted treatment of chronic patellar tendinopathy reduce pain and restore function? *Clinical orthopaedics and related research.* 2012;470(4):993-997.
13. Schmid MR, Hodler J, Cathrein P, Duewell S, Jacob HA, Romero J. Is impingement the cause of jumper's knee? Dynamic and static magnetic resonance imaging of patellar tendinitis in an open-configuration system. *Am J Sports Med.* 2002;30(3):388-395.
14. Shalaby M, Almekinders LC. Patellar tendinitis: the significance of magnetic resonance imaging findings. *Am J Sports Med.* 1999;27(3):345-349.
15. Johnson DP, Wakeley CJ, Watt I. Magnetic resonance imaging of patellar tendonitis. *The Journal of bone and joint surgery British volume.* 1996;78:452-457.
16. Khan KM, Bonar F, Desmond PM, et al. Patellar tendinosis (jumper's knee): findings at histopathologic examination, US, and MR imaging. *Radiology.* 1996;200(3):821-827.
17. Cook JL, Khan KM, Harcourt PR, et al. Patellar tendon ultrasonography in asymptomatic active athletes reveals hypoechoic regions: a study of 320 tendons. Victorian Institute of Sport Tendon Study Group. *Clin J Sport Med.* 1998;8(2):73-77.
18. Yu JS, Popp JE, Kaeding CC, Lucas J. Correlation of MR imaging and pathologic findings in athletes undergoing surgery for chronic patellar tendinosis. *Am J Roentgenol.* 1995;165:115-118.
19. Hansen P, Haraldsson BT, Aagaard P, et al. Lower strength of the human posterior patellar tendon seems unrelated to mature collagen cross-linking and fibril morphology. *Journal of applied physiology.* 2010;108(1):47-52.
20. Haraldsson BT, Aagaard P, Krogsgaard M, Alkjaer T, Kjaer M, Magnusson SP. Region-specific mechanical properties of the human patella tendon. *Journal of applied physiology.* 2005;98(3):1006-1012.
21. Lavagnino M, Arnoczky SP, Elvin N, Dodds J. Patellar tendon strain is increased at the site of the jumper's knee lesion during knee flexion and tendon loading: results and cadaveric testing of a computational model. *Am J Sports Med.* 2008;36(11):2110-2118.
22. Allen GM, Tauro PG, Ostlere SJ. Proximal patellar tendinosis and abnormalities of patellar tracking. *Skeletal Radiol.* 1999;28:220-223.
23. Lavagnino M, Arnoczky SP, Dodds J, Elvin N. Infrapatellar Straps Decrease Patellar Tendon Strain at the Site of the Jumper's Knee Lesion: A Computational Analysis Based on Radiographic Measurements. *Sports health.* 2011;3(3):296-302.
24. Blazina ME, Kerlan RK, Jobe FW, Carter VS, Carlson GJ. Jumper's knee. *The Orthopedic clinics of North America.* 1973;4(3):665-678.
25. Dejour D, Reynaud P, Lecoultre B. Douleurs et instabilité rotulienne. Essai de classification. *Med et Hyg.* 1998;56:1466-1471.
26. Pfirrmann CW, Zanetti M, Romero J, Hodler J. Femoral trochlear dysplasia: MR findings. *Radiology.* 2000;216(3):858-864.

27. Carrillon Y, Abidi H, Dejour D, Fantino O, Moyen B, Tran-Minh VA. Patellar instability: assessment on MR images by measuring the lateral trochlear inclination - initial experience. *Radiology.* 2000;216(2):582-585.
28. Biedert RM, Netzer P, Gal I, Sigg A, Tscholl PM. The lateral condyle index: a new index for assessing the length of the lateral articular trochlea as predisposing factor for patellar instability. *Int Orthop.* 2011;35(9):1327-1331.
29. Biedert RM, Bachmann M. Anterior-posterior trochlear measurements of normal and dysplastic trochlea by axial magnetic resonance imaging. *Knee Surg Sports Traumatol Arthrosc.* 2009;17:1225-1230.
30. Barnett AJ, Prentice M, Mandalia V, Wakeley CJ, Eldridge JD. Patellar height measurement in trochlear dysplasia. *Knee Surg Sports Traumatol Arthrosc.* 2009;17(12):1412-1415.
31. Bull AMJ, Katchburian MV, Shih YF, Amis AA. Standardisation of the description of patellofemoral motion and comparison between different techniques. *Knee Surg Sports Traumatol Arthrosc.* 2002;10:184-193.
32. Schoettle PB, Zanetti M, Seifert B, Pfirrmann CW, Fucentese SF, Romero J. The tibial tuberosity-trochlear groove distance; a comparative study between CT and MRI scanning. *Knee.* 2006;13(1):26-31.
33. Couppé C, Hansen P, Kongsgaard M, et al. Mechanical properties and collagen cross-linking of the patellar tendon in old and young men. *J Appl Physiol.* 2009;107:880-886.
34. Kongsgaard M, Reitelseder S, Pedersen TG, et al. Region specific patellar tendon hypertrophy in humans following resistance training. *Acta Physiol.* 2007;191:111-121.
35. Müller W. *Das Knie.* Heidelberg: Springer-Verlag; 1982.
36. Dejour H, Walch G, Neyret P, Adeleine P. [Dysplasia of the femoral trochlea]. *Rev Chir Orthop Reparatrice Appar Mot.* 1990;76(1):45-54.
37. Kamel M, Eid H, Mansour R. Ultrasound detection of knee patellar enthesitis: a comparison with magnetic resonance imaging. *Ann Rheum Dis.* 2004;63:213-214.
38. Edwards S, Steele JR, McGhee DE, Beattie S, Purdam C, Cook JL. Landing strategies of athletes with an asymptomatic patellar tendon abnormality. *Med Sci Sports Exerc.* 2010;42(11):2072-2080.
39. Lian O, Scott A, Engebretsen L, Bahr R, Duronio V, Khan K. Excessive apoptosis in patellar tendinopathy in athletes. *Am J Sports Med.* 2007;35(4):605-611.
40. Dejour H, Walch G, Nove-JOsserand L, Guier C. Factors of patellar instability: an anatomic radiographic study. *Knee Surg Sports Traumatol Arthrosc.* 1994;2(1):19-26.
41. Charles MD, Haloman S, Chen L, Ward SR, Fithian D, Afra R. Magnetic resonance imaging-based topographical differences between control and recurrent patellofemoral instability patients. *Am J Sports Med.* 2013;41(2):374-384.
42. Nelitz M, Lippacher S, Reichel H, Dornacher D. Evaluation of trochlear dysplasia using MRI: correlation between the classification system of Dejour and objective parameters of trochlear dysplasia. *Knee Surg Sports Traumatol Arthrosc.* 2014;22(1):120-127.
43. Teng HL, Chen YJ, Powers CM. Predictors of patellar alignment during weight bearing: an examination of patellar height and trochlear geometry. *Knee.* 2014;21(1):142-146.
44. Servien E, Ait Si Selmi T, Neyret P. [Study of the patellar apex in objective patellar dislocation]. *Rev Chir Orthop Reparatrice Appar Mot.* 2003;89(7):605-612.
45. Culvenor AG, Cook JL, Warden SJ, Crossley KM. Infrapatellar fat pad size, but not patellar alignment, is associated with patellar tendinopathy. *Scand J Med Sci Sports.* 2011;21(6):e405-411.
46. Yiannakopoulos CK, Mataragas E, Antonogiannakis E. The effect of quadriceps contraction during weight-bearing on four patellar height indices. *The Journal of bone and joint surgery British volume.* 2008;90(7):870-873.

47. Schueda MA, Astur DC, Bier RS, Bier DS, Astur N, Cohen M. Use of computed tomography to determine the risk of patellar dislocation in 921 patients with patellar instability. *Open Access Journal of Sports Medicine.* 2015;6:55-62.
48. Ward SR, Terk MR, Powers CM. Patella alta: association with patellofemoral alignment and changes in contact area during weight-bearing. *J Bone Joint Surg.* 2007;89:1749-1755.
49. Luyckx T, Didden K, Vandenneucker H, Labey L, Innocenti B, Bellemans J. Is there a biomechanical explanation for anterior knee pain in patients with patella alta? *J Bone Joint Surg.* 2009;91-B(3):344-350.

	Pathologic cut-off value	Patellar tendon partial tear (N = 47)			Control group (N = 87)			Mann-Whitney Test	Chi^2-Test	Inter-rater Reliability
		(mean +/- SD)	*(No. of pathologic)*		*(mean +/- SD)*	*(No. of pathologic)*		*(for means)*	*(No. of pathologic)*	*(ICC)*
TROCHLEA										
Sulcus angle	> 145° *	151.7° +/- 3.5	32	68.1%	149.4° +/- 7.3	62	71.3%	p = 0.31	p = 0.11	0.83
Lateral trochlear inclination	< 11°	19.0° +/- 7.3	6	12.8%	17.3° +/- 5.3	7	8.0%	p = 0.16	p = 0.216	0.92
AP-Index										
medial	-	0.70 +/- 0.07			0.73 +/- 0.04			p < 0.001		0.98
central	-	0.69 +/- 0.07			0.71 +/- 0.04			p < 0.001		0.92
lateral	< 0.77	0.77 +/- 0.08	22	46.8%	0.78 +/- 0.04	32	36.8%	p = 0.017	p = 0.10	0.96
Lateral condylar index	< 0.9	0.91+/- 0.07	17	39.5%	0.91 +/-0.07	39	44.8%	p = 0.96	p = 0.466	0.83
Facet ratio (med/lat)	< 0.4	0.39 +/- 0.09	26	55.3%	0.48 +/- 0.1	18	20.7%	p < 0.001	p < 0.001	0.38
PATELLA										
Height										
- Caton-Deschamp Index	> 1.2	1.17 +/- 0.17	22	46.8%	1.12 +/- 0.16	25	28.7%	p = 0.056	p = 0.051	0.91
- Insall Salvati Index	> 1.2	1.18 +/- 0.21	20	42.6%	1.07 +/- 0.16	19	21.8%	p = 0.004	p = 0.012	0.66
- Patellotrochlear Index	< 0.18	0.33 +/- 0.12	5	10.6%	0.37 +/- 0.12	5	5.7%	p = 0.014	p = 0.004	0.85
Patellar tilt	> 20°	8.8+ +/- 6.2	3	6.4%	9.1° +/- 5.1	1	1.1%	p = 0.36	p = 0.787	0.72
TT-TG Distance	> 15 mm	12.0mm +/- 3.5	11	23.4%	9.9mm +/- 3.7	11	12.6%	p = 0.002	p = 0.172	0.83
	> 20 mm		1	2.1%		0	0.0%